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(19)

(54) SYSTEM FOR REGULATING A FUEL CELL UNIT

(71) We, ROBERT BOSCH GmbH, a German Company, of 4, Breitscheidstrasse, Stuttgart W, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a system for regulating at any one time the operating condition of a unit comprising one or a plurality of electro-chemical fuel cells which are operated by fuel dissolved in the electrolyte and a gaseous oxidizing agent.

It is known to control the temperature in a hydrogen/oxygen fuel cell in conjunction with a hydrogen generator by cooling the electrolyte by the hydrogen fed to the cell and to flush the cells with hydrogen at specific intervals of time in order to remove impurities.

It is also known to control the power output and the output voltages in a hydrogen/oxygen fuel cell.

These methods have the disadvantage that only some of the operating parameters which have to be observed for the continuous operation of a fuel cell under optimum conditions, are measured and used for the purpose of control, so that a permanently high power output is not ensured for the continuous operation of such a cell.

The present invention provides a system which enables a fuel cell unit to be operated permanently under optimum operating conditions and which enables the maximum power to be taken from the said unit at all times.

In accordance with the present invention there is provided a system for regulating the operating condition of a unit comprising at least one electro-chemical fuel cell which is operated by fuel dissolved in the electrolyte and a gaseous oxidising agent, electrical signals characteristic of the electrode potential of the cell, the temperature of the cell, and the terminal voltage and current of the unit being transmitted to an electronic control device, the terminal voltage and current of the unit being used by the control device to derive a signal representative of the power output of the unit, all the signals enabling the electronic control device to regulate each of a plurality of regulating processes for maintaining the operation of the unit at its optimum condition, the first regulating process being the intermittent supply of a mixture of fuel and electrolyte to the cell when the working temperature is exceeded, the supply of fuel and electrolyte maintaining the temperature at or about the optimum value, the second regulating process being the intermittent supply of a mixture of fuel and electrolyte to the cell when the electrode potential of the cell drops below a preset limiting value, the third regulating process being the supplying of a mixture of fuel and electrolyte to the cell by the action of an electronic time switch element in time intervals which are controlled in dependence upon the power output, the third regulating process only being operative if processes one or two have not occurred, a fourth regulating process being the opening of an oxygen outlet valve by the action of the electronic time switch element in time intervals controlled by the power output and/or electrode potential of the cell, the electrode of the cell being rinsed in a stream of oxygen, and a fifth regulating process whereby the terminal output voltage is kept constantly at a fixed value independently of the power output, the electronic control device also serves to switch on a limiting resistor when the power output from the unit exceeds a predetermined value, the limiting resistor serving to prevent the cell from becoming overloaded, and an electronically regulated load circuit is also provided for rapidly heating the cell to its optimum working temperature.

To prevent current flowing from a cell producing a high voltage into a cell of lower voltage when a plurality of parallel-connected

cells are used, the cells are decoupled by interposing an electrical network, two diodes in the simplest case, or by connecting the cells in control circuits which are isolated from each other.

The potentials of specially prepared and thus especially sensitive individual cells are used as measured potentials. The high sensitivity of these cells is attained by reducing the catalyst content of the electrodes to about 40% of the quantity customary in working electrodes.

The invention will now be described further by way of example, with reference to the accompanying drawings, in which:—

Fig. 1 is a block diagram of a fuel cell unit, and

Fig. 2 is a block circuit diagram of an electronic control device and the elements controlled thereby.

Referring to Fig. 1, a fuel cell unit comprises two fuel cells 1, an electronic control device 2, an oxygen bottle 3, a fuel/electrolyte reservoir 4, and electrolyte pumps 5. Temperature sensors and specially prepared individual cells whose potentials are used for measuring electrode potentials of the fuel cells are fitted into the fuel cells, 1, and are connected to the control device 2 by leads 6 and 7. Furthermore, the current supply leads 8 lead from the cells 1 to the control device 2 by way of diodes 9. Leads 10 lead outwardly from the control device 2 by way of an ammeter 11 and a voltmeter 12 to the connection terminals for tapping the working voltage. The terminal voltage and current of the unit as sensed by the voltmeter 12 and the ammeter 11 is used by the control device 2 to derive a signal representative of power output. A gas line 13 leads from the oxygen bottle 3 by way of a precision control valve 14 and a manometer 15 into the cells 1 and then into the fuel/electrolyte reservoir 4 by way of an oxygen outlet valve 16. A conduit 17 leads from the reservoir 4 by way of the electrolyte pumps 5 to the cells 1 and from there back into the reservoir 4. The oxygen outlet valve 16 and the electrolyte pumps 5 are controlled by the electronic control device 2 by way of electrical leads 18 and 19 and are supplied with current which is produced by the fuel cells 1 themselves.

To put the unit into operation, the oxygen bottle 3 is filled and is connected to the supply line 13. A fuel/electrolyte mixture comprising 4 kilogrammes potassium hydroxide and 1.5 litres methanol is made up to 12 litres with distilled water and filled into the fuel/electrolyte reservoir 4. Such a charge is adequate for 24 hours continuous operation at full load, and for a correspondingly longer time at part load. The main valve and the pressure-reducing valve of the oxygen bottle are now opened successively and an oxygen excess pressure of 0.2 atmospheres, readable on the manometer 15, is set by means of the precision control valve 14. An output stage switch 20 (Fig. 2) is now switched to the desired output, for example 100 watts. As may be seen from Fig. 2, the switch 20 acts upon the temperature controller 21 by setting a nominal temperature value (70°C in this case) corresponding to this output. An "ON" button fitted into the front panel of the controller is now pressed, and the volt meter 12 indicates voltage. To flush the cells and to check that the electrolyte pumps 5 are operating satisfactorily, the pumps are actuated manually for a short time by pressing a button "ELECTROLYTE". To blow out any liquid which has accumulated in the gas line 13, the oxygen outlet valve 16 is actuated several times by pressing a button "OXYGEN". The fuel cell unit supplies sufficient current at room temperature to operate the two electrically operated devices 5 and 16.

If it is desired to attain the operating temperature as rapidly as possible, the voltage switch 23 is switched to the 10 volts stage. The cells are thereby loaded at a lower voltage and thus with a higher amperage by an internal electronically controlled load circuit 24 until the operating temperature is attained. A heating current controller 25 ensures that, in conjunction with the temperature controller 21, the maximum admissible amperage always sets in for the prevailing temperature. It is also possible to connect a load to the connection terminals during the heating-up operation. The load is then included in the load circuit, so that the electrical data of this circuit varies accordingly. The diodes 9 located in the current supply leads 8 between the fuel cells 1 and the control device 2, and the electrical decoupling of the parallel-connected cells achieved thereby, are provided for preventing current flowing from cells having a higher voltage into cells having a lower voltage, thus reducing the power of the unit, in the case where individual cells have, for whatever reason, lower voltages than the other cells.

When the operating temperature has been attained, as indicated by a pilot lamp going out, the voltage switch 23 is switched back to 12 volts and the full output can be tapped without further supervision of the unit, since the electronic controller now takes over all further operations. The output voltage is stabilized by a voltage regulator 26 which is known per se and which is in the form of a switching regulator. If the temperature exceeds the nominal value, the temperature controller 21 switches on the electrolyte pumps 5 for a specific interval of time which is controlled by an electronic time switching elements 27, so that cool liquid is metered from the fuel/electrolyte reservoir 4. A ratio of fuel to electrolyte is eventually obtained so that the fuel

content of the cell helps to maintain the temperature at its nominal value. However, if the power taken from the cells is too small, the joule heating produced is inadequate to maintain or exceed the nominal temperature and thus initiate a supply or fuel. The solution in the cells becomes deficient in fuel, so that satisfactory operation is no longer obtained. To supply the cells with fuel even in such cases, the electronic time switching element 27 is governed by the power output in such a manner that the electrolyte pumps 5 are switched on at specific intervals of time by way of the electronic time switching element 27 and fuel thus flows into the cells. However, if fuel-electrolyte mixture is fed to the cells by action of the temperature controller 21, the electronic time switching element 27 is switched into its corresponding condition with regard to this control task.

The temperature and power output are linked together very closely, the power output being dependent upon the temperature, i.e. each power output has an optimum working temperature. As is shown in Fig. 2, the temperature regulator 21 is controlled by the output stage switch 20, which enables specific output ranges to be adjusted (e.g. 0—50, 50—80, 80—100 watts). The higher the desired temperature at which the temperature regulator 21 switches on the fuel-electrolyte pump 5, so the higher the output range to which the stage switch 20 has to be adjusted. The temperature is measured by way of thermistors 22 which are incorporated in the fuel cells and are temperature dependent. A minimum value for the potentials of the individual cells is preset in the electronic control device, and when the potentials of the individual cells fall below this minimum value the fuel electrolyte pump is switched on. If no signal, which switches on the fuel-electrolyte pump, comes from either the temperature controller 21 or the individual cells, then no corresponding signal will be received by the electronic control device. Under these circumstances the electronic time switch element 27 maintains the fuel supply to the cells by switching on the fuel-electrolyte pump 5 at specific time intervals which are also in turn controlled by the power output.

As shown in Fig. 1 only one lead 19 passes from the electronic control device to the two electrolyte pumps 5. Thus the two parallel-connected cells are supplied by a respective fuel-electrolyte pump, both of these pumps being controlled in a parallel manner. It would therefore be just as possible to use only one pump having an appropriately larger output in the case shown in Fig. 1. It is possible for each fuel cell, where there is a plurality of parallel-connected cells, to have its own electronic control device. In this case, each pump would be controlled individually.

The oxygen outlet valve 16 is opened periodically to clean the gas space and the electrodes of electrolyte which has intruded and of foreign gases originating from the oxygen. The oxygen excess pressure is thereby relieved for 1 second and oxygen passes along the gas side of the electrodes and entrains any liquid film or gaseous impurities present on the electrodes. Furthermore, in this way, the three-phase limit (solid-liquid-gas) can set in the most reliable manner. Under normal operating conditions the oxygen outlet valve 16 is opened every 30 minutes by the electronic time switching element 27. However, if the power output of the unit is high, the oxygen outlet valve 16 can be controlled by, the power output and opened at an earlier instant. The electronic time switching element 27 is in this case also brought into its corresponding condition with regard to the opening of the valve 16, i.e. its condition 30 minutes before the valve 16 is due to be opened again.

The potentials of the built-in, specially sensitive measuring cells are continuously monitored by the electronic controller. If one or both of the potentials fall(s) below the preset value for examples 200 mV, a potential monitor 28 first of all initiates the opening of the oxygen outlet valve 16 and then initiates the supplying of fuel by switching on the electrolyte pumps 5. If these measures do not cause the potential to increase again, as might occur if there is a deficiency of fuel in the electrolyte supply or if no further oxygen is delivered, the load is isolated from the apparatus and the whole system for regulating the operation conditions of the cell units is switched off by way of a relay 29. The potential monitor 28 thereby serves as a last safety device, but is necessary for the continuous operation of the unit in order to protect the electrodes against damage.

If too high a power output is taken from the unit, a current limiting resistor 30 comes automatically into operation causing the resistor 30 to be connected in series with the load. The switching on of the resistor 30 prevents the cell from becoming overloaded.

If the temperature in a cell exceeds a limiting value detrimental to the electrodes, a built-in excess-temperature monitor 31 switches the whole system off by way of the relay 29. Too high a temperature can occur if, for example, one of the electrolyte pumps 5 fails, so that one of the cells is no longer cooled.

The described system of the present invention has the advantage that a fuel cell unit is regulated and controlled fully automatically to the extent where it can be operated for about 24 hours without supervision. When this period has expired, it is necessary merely to replace the fuel/electrolyte mixture and the oxygen bottle. No external source of cur-

rent is required to put the system into operation. If any faults occur during operation, the automatic control arrangement ensures that measures are taken to prevent damage to the electrodes of the individual cells. The unit can be put into operation again immediately after the faults have been rectified. A unit which operates in accordance with the present invention and which has a rated output of 100 watts at 65° to 70°C and a spatial requirement of 0.16 m^3 is still easily transportable at a weight of 90 kilogrammes in the filled state.

WHAT WE CLAIM IS:—

1. A system for regulating the operating condition of a unit comprising at least one electro-chemical fuel cell which is operated by fuel dissolved in the electrolyte and a gaseous oxidising agent, electrical signals characteristic of the electrode potential of the cell, the temperature of the cell, and the terminal voltage and current of the unit being transmitted to an electronic control device, the terminal voltage and current of the unit being used by the control device to derive a signal representative of the power output of the unit, all the signals enabling the electronic control device to regulate each of a plurality of regulating processes for maintaining the operation of the unit at its optimum condition, the first regulating process being the intermittent supplying of a mixture of fuel and electrolyte to the cell when the working temperature is exceeded, the supply of fuel and electrolyte maintaining the temperature at or about the optimum value, the second regulating process being the intermittent supplying of a mixture of fuel and electrolyte to the cell when the electrode potential of the cell drops below a preset limiting value, the third regulating process being the supplying of a mixture of fuel and electrolyte to the cell by the action of an electronic time switch element in time intervals which are controlled in dependence upon the power output, the third regulating process only being operative if processes one or two have not occurred, a fourth regulating process being the opening of an oxygen outlet valve by the action of the electronic time switch element in time intervals controlled by the power output and/or electrode potential of the cell, the electrodes of the cell being rinsed in a stream of oxygen, and a fifth regulating process whereby the terminal output voltage is kept constantly at a fixed value independently of the power output, the electronic control device also serves to switch on a limiting resistor when the power output from the unit exceeds a predetermined value, the limiting resistor serving to prevent the cell from becoming overloaded, and an electronically regulated load circuit is also provided for rapidly heating the cell to its optimum working temperature.

2. A system as claimed in claim 1 in which when a plurality of parallel-connected fuel cells are used, the fuel cells are electrically decoupled relative to each other.

3. A system as claimed in claim 1 in which when a plurality of parallel-connected fuel cells are used, each fuel cell has its own electronic control device.

4. A system as claimed in any of claims 1 to 3 in which specially prepared individual cells are fitted into the fuel cells, the potentials of the individual cells being used for measuring the electrode potentials of the fuel cells, the electrodes of the individual cells having a catalyst content smaller than that in the working electrodes of the fuel cell.

5. A system as claimed in any of claims 1 to 4 in which the electronic time switch element is switched into a condition simultaneously with the supply of fuel and electrolyte mixture to the fuel cell, the condition being such that the time switch element is at the beginning of a time interval after which it will cause the electrolyte pumps to be switched on again and the fuel and electrolyte mixture will flow into the fuel cell.

6. A system for regulating the operating conditions of a fuel cell unit constructed substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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1304092 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

Fig. 1

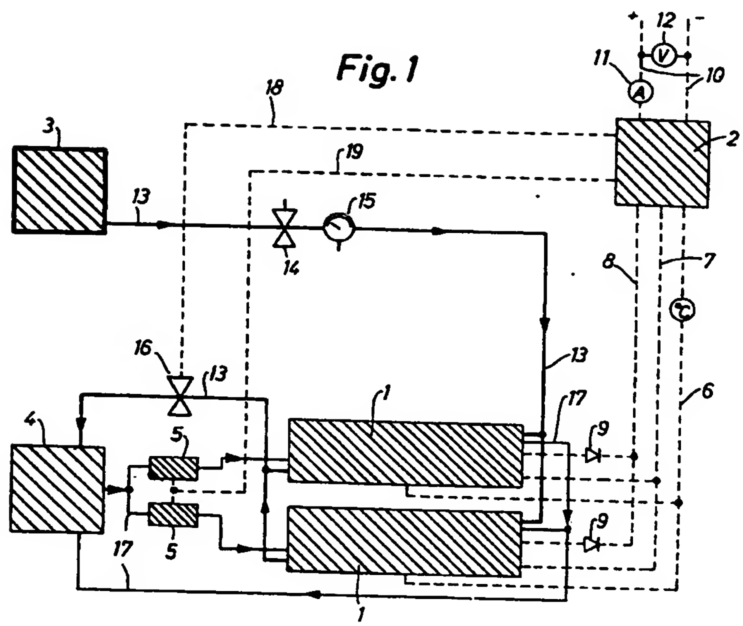
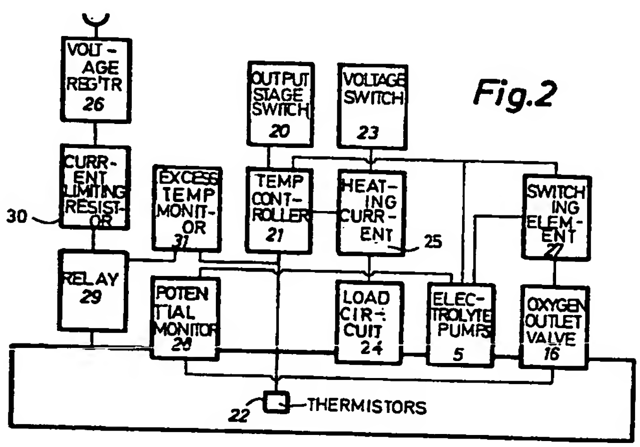


Fig. 2



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